

GROUNDWATER INFORMATION SHEET

Salinity

Salinity is a measure of the amount of dissolved particles and ions in water. There are several different ways to measure salinity; the two most frequently used analyses are described below:

- Total Dissolved Solids (TDS): TDS is a measure of all dissolved substances in water, including organic and suspended particles that can pass through a very small filter. TDS is measured in a laboratory and reported as mg/L.
- Electrical Conductivity (EC): The ability of an electric current to pass through water is proportional to the amount of dissolved salts in the water – specifically, the amount of charged (ionic) particles. EC is a measure of the concentration of dissolved ions in water, and is reported in $\mu\text{mhos/cm}$ (micromhos per centimeter) or $\mu\text{S/cm}$ (microsiemens per centimeter). A μmho is equivalent to a μS . EC can be measured in a laboratory or with an inexpensive field meter. Also called specific conductance or specific conductivity.

“Salinity” can include hundreds of different ions; however, relatively few make up most of the dissolved material in water: chloride (Cl^-), sodium (Na^+), nitrate (NO_3^-), calcium (Ca^{+2}), magnesium (Mg^{+2}), bicarbonate (HCO_3^-), and sulfate (SO_4^{-2}). The concentrations of boron (B), bromide (Br), iron (Fe), and other trace ions can be locally important.

Approximate Total Dissolved Solids (TDS) Values in Natural Waters	
Natural Water	TDS (mg/L)
Precipitation	10 mg/L
Pristine Freshwater Lakes and Rivers	10 to 200 mg/L
Amazon River	40 mg/L
State Water Project Deliveries	275 mg/L
Lakes Impacted by Road Salt Application	400 mg/L
Agricultural Impact to Sensitive Crops	500 mg/L
Colorado River Water	700 mg/L
California Drinking Water Limit*	1,000 mg/L
Average Seawater	35,000 mg/L
Brines	>50,000 mg/L
Groundwater	100 to >50,000 mg/L
*Secondary Maximum Contaminant Level. mg/L = milligrams per liter, or parts per million (ppm)	

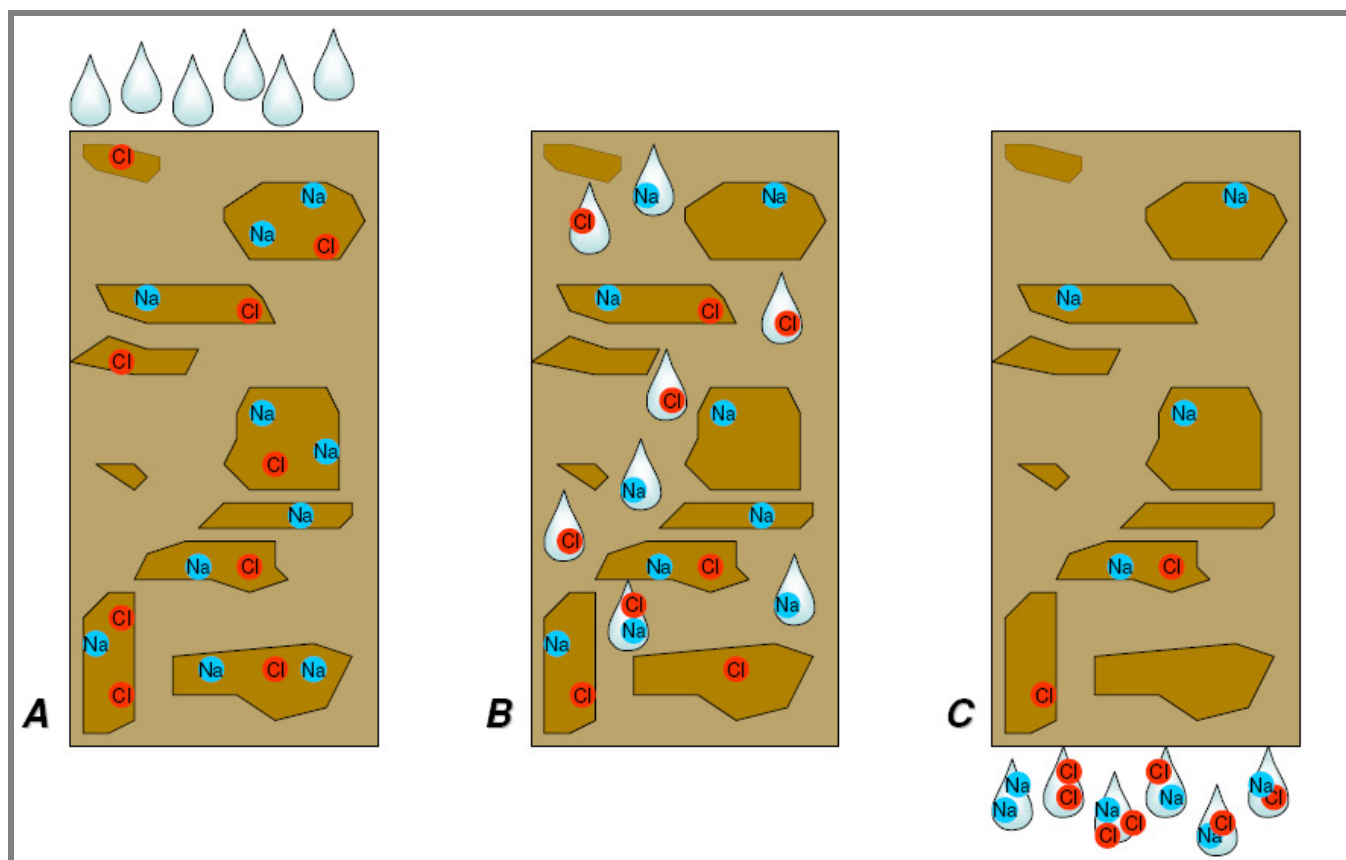
The clarity of water is unrelated to salinity (TDS). For example, visibility in the ocean can be hundreds of feet, even though ocean water has a very high salinity (TDS of 35,000 mg/L). On the other hand, water with low visibility like the Mississippi River can have low TDS (~200 mg/L) because the particles that obscure visibility are not *dissolved*, and can be easily filtered from the water. The amount of dissolved material in natural waters is a complex function of climate, land-use patterns, human activity in the watershed, and geologic make-up of the hydrologic basin.

Adverse Effects

High concentrations of salts can damage crops, affect plant growth, degrade drinking water, and damage industrial equipment. High concentrations of nitrate are a health threat. Most salts do not naturally degrade, and can remain in groundwater for decades. The economic cost of increased groundwater and surface water salinity to California – manifested in fallowed farmland, unsuitable drinking water, and environmental degradation – is estimated in the millions of dollars annually.

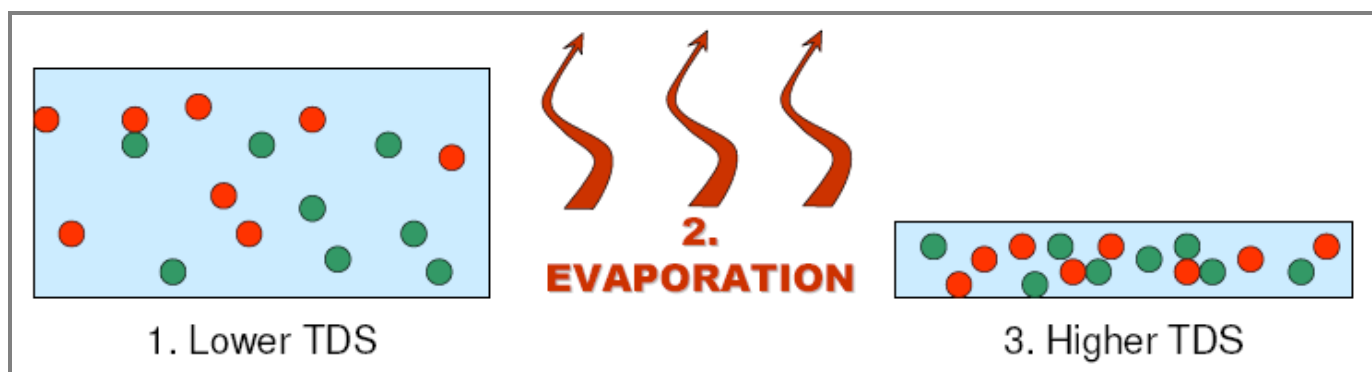
Sources of Salt

Salts enter groundwater naturally through dissolution of soil, rock, and organic material. A schematic illustrating how dissolution occurs is shown below.



Dissolution of Natural Materials: Water is introduced to the soil from irrigation or rain (A). As the water percolates downwards it dissolves ionic and non-ionic particles from minerals in the soil column (B). The water that leaves the soil to the underlying groundwater is enriched in salts (C).

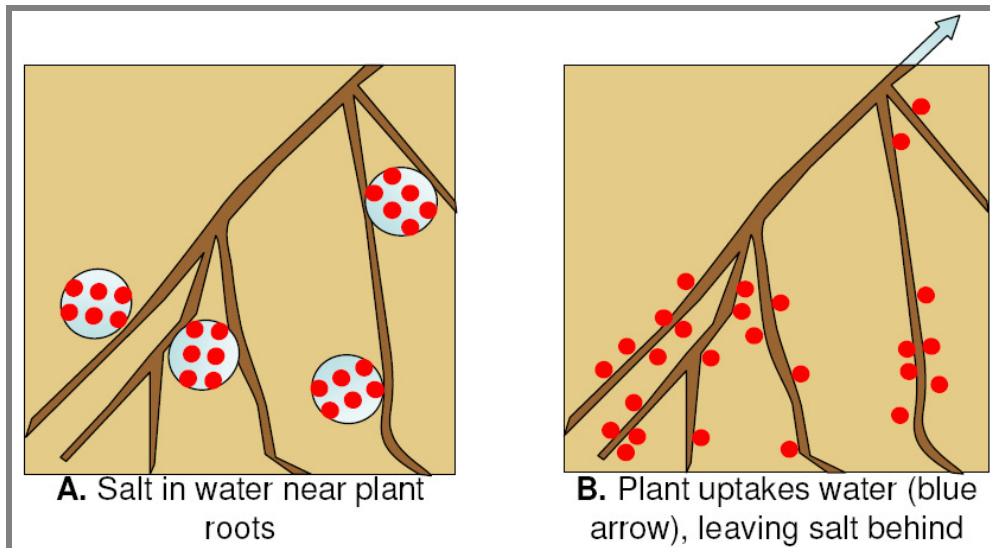
The concentration of salts in surface and groundwater can increase in several ways. *Increased dissolution* can increase salinity levels. *Evaporative enrichment* is the process of increasing salinity levels in surface or groundwater by removing water via evaporation. For example, irrigation water is often applied to crops during the summer when evaporation rates are highest. As water molecules evaporate into the atmosphere, salts remain behind in the irrigation water. This irrigation water can percolate into the underlying groundwater. If the groundwater is later pumped and used for additional irrigation, the evaporation cycle is repeated and salinity levels will continue to increase. *Dryland salinity* affects soils when groundwater is brought to the surface by capillary action; evaporation removes water and leaves salt at the soil surface.



Evaporative Enrichment: As water evaporates, salts will remain behind. As a result, the concentration of salts in water with a relatively low starting salinity (TDS) can increase simply due to evaporation. Irrigation can result in significant increases in salinity through evaporative enrichment.

Water uptake by plants can also increase soil salinity. Water percolating through the ground has salts dissolved in it. Plant roots work by taking in water while excluding salts and other non-nutrients. The excluded salts will gradually build up around the roots, and must be periodically “flushed” from the root zone or plant death may occur. In natural systems, the types of plants found in a specific environment are adapted for naturally-occurring soil salinities. In many agricultural areas, salts are flushed from the soil by applying irrigation water. The salts that are flushed from the soil either enter groundwater or are discharged to surficial drains.

Human activities also affect salinity levels in ground and surface water. Application of synthetic fertilizers, manures, and wastewater treatment facilities can all contribute salt to surface and groundwater. Nitrogen is a necessary nutrient for plant growth, and nitrogen fertilizers are typically in the form of the salt nitrate. If excess nitrate fertilizer is applied to a field, the nitrate not used by plants can dissolve and move to groundwater. Manure from confined animal facilities is enriched in nutrients and other salts, and can also increase salinity levels in receiving waters. Domestic wastewater is typically enriched in salts due to household activities such as washing and water softening. Most water treatment facilities cannot remove salt. As a result, discharges from these facilities can increase surface and groundwater salinity.



Plants Increase Soil Salinity: Soil pore water used by plants contains dissolved solids and other salts (A). Water uptake by roots will exclude salts and dissolved solids. Over time, as water is moved upwards through the roots to the rest of the plant, salts will build up in the soil surrounding the roots (B). Salts must be periodically flushed from the soil; otherwise, rising soil salinities may cause the plant to die.

Summary of Salinity Sources:

- **Agriculture:** Evaporation of irrigation water will remove water and leave salts behind. More salt can be dissolved from soil as irrigation water percolates downward. Plants can naturally increase soil salinity as they uptake water and exclude salts. Application of synthetic fertilizers can increase nitrate concentrations in surface and groundwater. Manure from confined animal facilities is enriched in nutrients and other salts, and can also increase salinity levels in receiving waters.
- **Municipal:** Detergents, water softeners, and industrial processes all use salts – wastewater discharged to POTWs and septic systems is often more salty than the original source water. Discharges from POTWs and septic systems can increase the salinity of receiving waters. Overwatering of lawns and residential use can also contribute to salinity.
- **Industrial:** Many industrial processes can increase salinity in process wastewater. Cooling towers, power plants, food processors, and canning facilities.
- **Natural:** Groundwater contains naturally-occurring salts from dissolving rocks and organic material. Some rocks dissolve very easily; groundwater in these areas can naturally be very high in salinity.

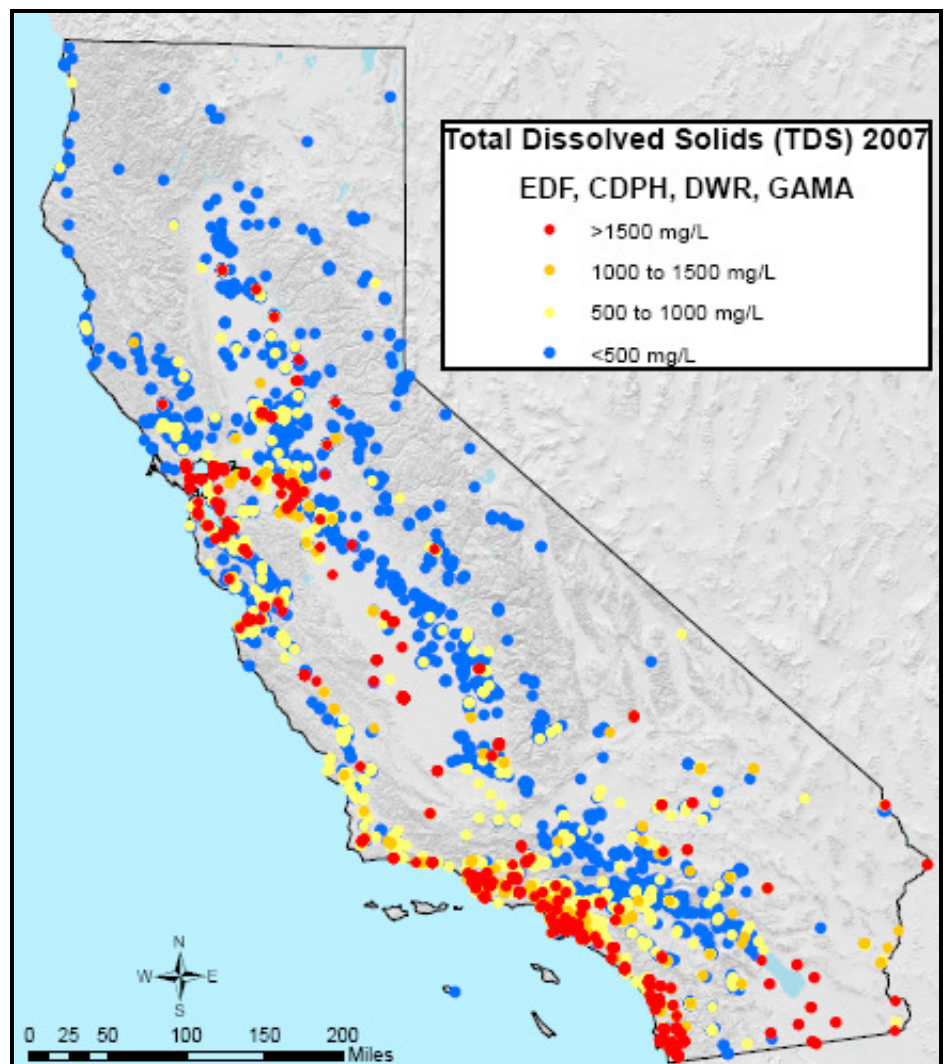
Drinking Water Standards for Salinity

The California Department of Public Health (CDPH) has established EC and TDS secondary maximum contaminant level (SMCL) drinking water standards for public water supplies. SMCLs are ranges set by CDPH for taste and odor thresholds; for TDS, the recommended SMCL is 500 mg/L, and the upper SMCL is 1,000 mg/L. For EC, the recommended SMCL is 900 $\mu\text{S}/\text{cm}$, and the upper SMCL is 1,600 $\mu\text{S}/\text{cm}$. EC and TDS also have short-term SMCLs that are generally allowed only under rare circumstances (2,200 $\mu\text{S}/\text{cm}$ and 1,500 mg/L, respectively).

A map of TDS in California's groundwater measured in 2007 is shown below. Specific areas with groundwater TDS concentrations above SMCLs are located along the southern coast, the Sacramento-San Joaquin Delta, the southern and western San Joaquin Valley, San Francisco Bay, and the Salton Sea area.

TDS in Groundwater, 2007

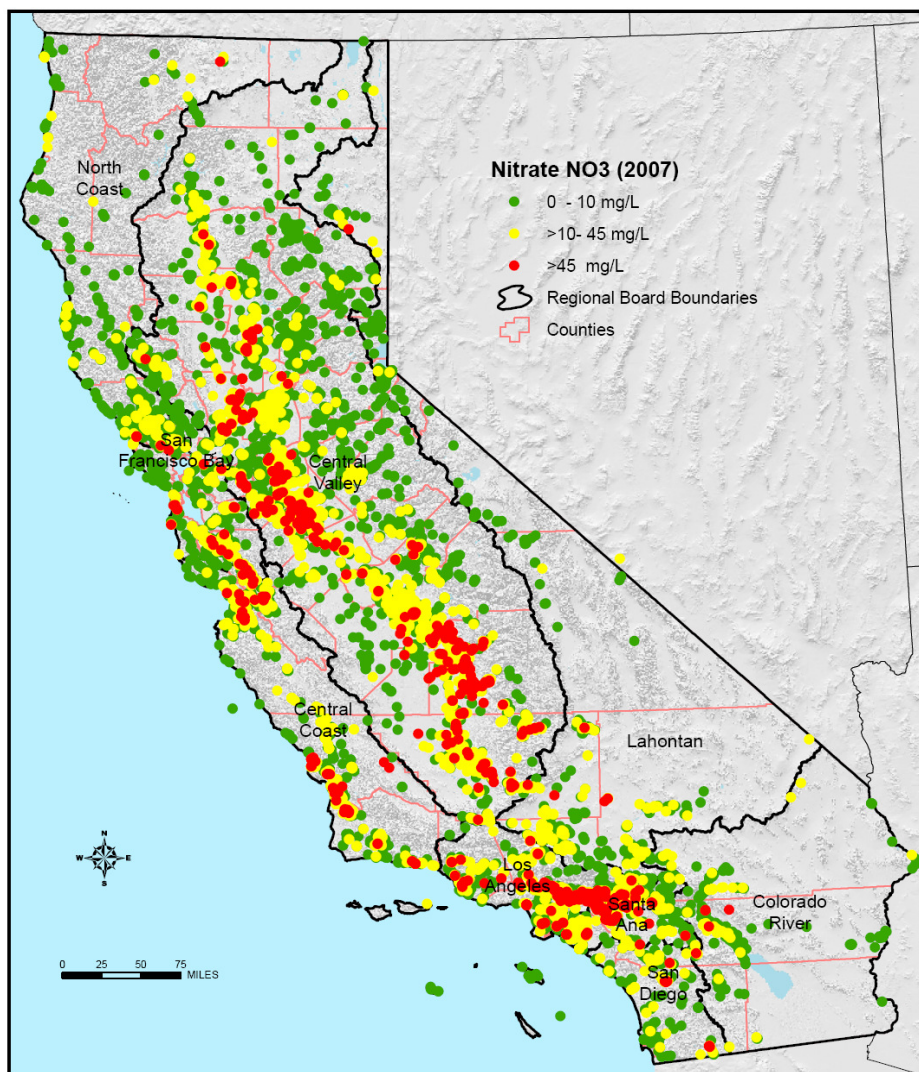
TDS concentrations using data from public supply wells (CDPH), environmental cleanup sites (SWRCB), Department of Water Resources (DWR), and the State Water Boards Groundwater Ambient Monitoring and Assessment (GAMA) Program. Red dots indicate wells where TDS concentrations are above short term public drinking water standards. Orange dots indicate wells where TDS concentrations are above upper limit public drinking water standards. Yellow dots indicate wells where TDS concentrations are above recommended public drinking water standards, and blue dots indicate wells below all public drinking water standards. Data source: GeoTracker GAMA.



Nitrate: A Unique Salt

Nitrate (NO_3^-) is formed naturally when nitrogen-containing organic compounds are broken down in the presence of oxygen. Nitrate is also produced in an industrial process during manufacture of synthetic fertilizers. High levels of nitrate in groundwater are associated with intense agricultural activity, septic systems, confined animal facilities, and wastewater treatment facilities. Nitrate is also one of the few salts that can be removed from water through a naturally occurring process (denitrification).

Nitrate is a health concern. Methemoglobinemia, or “blue baby syndrome,” can affect infants when elevated nitrate levels in drinking water cause a decrease in the oxygen carrying capacity of blood. The current drinking water standard of 45 mg/L as NO_3 is specifically designed to protect infants. High levels of nitrate in drinking water may be unhealthy for pregnant women. Livestock can also be sensitive to high levels of nitrate in their drinking water.



Nitrate in Groundwater, 2007

Nitrate concentrations using data from public supply wells (CDPH), environmental monitoring wells (SWRCB), DWR, and GAMA. Red dots indicate wells with nitrate concentrations above public drinking water standards (>45 mg/L as NO_3); yellow dots show nitrate concentrations from 10 to 45 mg/L (as NO_3); green dots show concentrations of nitrate less than 10 mg/L (as NO_3). Data source: GeoTracker GAMA.

Water Softeners

Water with high concentrations of calcium and magnesium is referred to as 'hard water.' Hard water – which can clog pipes and reduce the lathering action of soaps – may be treated using a water softener that exchanges magnesium and calcium ions for sodium or potassium ions. In order for the water softener to function properly, the exchange resin must be periodically recharged using a highly saline brine. The brine used in the regeneration process is discharged to municipal sewage systems or a septic leachfield. Wide-spread use of water softeners has been known to significantly increase salinity levels in wastewater sent to water treatment facilities.

Seawater Intrusion

In some locations, groundwater overdraft (overpumping) has caused the natural groundwater gradient to reverse and has allowed seawater to intrude coastal aquifers that historically contained only fresh water. Seawater intrusion can ruin drinking water and irrigation wells, and render some areas unsuitable for continued agriculture. The Salinas groundwater basin, Santa Clara Valley (San Francisco Bay), and the Los Angeles basin have experienced significant seawater intrusion into drinking water aquifers. To prevent additional seawater intrusion, communities have installed subsurface barriers and injection wells to restore natural groundwater.

Salinity Challenges

Addressing salinity in California's waters is a challenge for California. Some generation of salt is unavoidable: public water works, industrial activities, food processors, and dairies are important parts of the economy and society – and can all increase salt loads to the State's waters. The following summarize efforts made to address salinity in California:

- The State's NDPES and WDR regulatory programs manage salt impacts to surface water and groundwater.
- Institution of preventative measures by local agencies, such as requiring more efficient water softeners and managing lawn fertilizer application.
- Reducing salt loads from imported irrigation water
- Development of technical advances in irrigated water and fertilizer application methods.
- Disposal of salts through brine lines, deep injection wells, lined landfills, and evaporation ponds.